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Device simulation of 17.3% efficient lead-free all-perovskite tandem solar cell

Jaya Madan, Shivani, Rahul Pandey*, Rajnish Sharma

VLSI Centre of Excellence, Chitkara University Institute of Engineering and Technology, Chitkara University, Punjab, India

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ABSTRACT

Present research paper brings forth the results of simulation-based studies carried out on all-perovskite tandem (both top and bottom subcells made up of perovskites) multijunction devices. The all-perovskite tandem structure presented in this work employs a wide bandgap perovskite, i.e., $Cs_2AgBi_{0.75}Sb_{0.25}Br_6$ (1.8 eV) and a narrow bandgap perovskite, i.e., $FACsPb_{0.5}Sn_{0.5}I_3$ (1.2 eV) as top and bottom cell respectively. An additional merit of the reported work is projection of lead (Pb)-free perovskite, $Cs_2AgBi_{0.75}Sb_{0.25}Br_6$ and low Pb content-based perovskite, $FACsPb_{0.5}Sn_{0.5}I_3$ based tandem solar cell. The viability of proposed tandem design is performed in two steps firstly, 1.8 eV perovskite-based top cell is simulated and calibrated to fit the state-of-the-art conversion efficiency of 10.1%, and then, 1.2 eV perovskite-based bottom cell is simulated to have a calibrated efficiency of 14.2%. After calibrating the standalone (top and bottom) subcells, both the devices are evaluated for tandem configuration. The current matching conditions between the top and bottom cell is obtained at different thicknesses of the absorber layer in both top and bottom subcell. The optimized thickness for perovskite, 380 nm for top cell and 400 nm for bottom cell are obtained for tandem configuration. Top and bottom cells (fed with the filtered spectrum) reflect the conversion efficiency of 10.01% and 7.36%, respectively. Overall, tandem design showed a conversion efficiency of 17.3% owing to an enhancement in open-circuit voltage (V_{OC}), which is 1.83 V.

1. Introduction

Single junction photovoltaic (PV) devices are unable to surpass Shockley–Queisser (SQ) single-junction limit predicted in 1961 (Shockley and Queisser, 1961). The limiting performance is mainly attributed to two factors; first, non-absorbed photons with energies lower than the bandgap. Second, thermalization losses, where the portion of photon energy in excess of that required to produce free electron-hole pairs leads to carrier thermalization and does not contribute to the useful output of the device. These losses can be mitigated by utilizing the incident spectrum in parts with the help of different solar cells made from the semiconducting material of the appropriate bandgap. In this approach, wide/narrow bandgap materials are used for top/bottom subcell for efficient utilization of the lower wavelength alongside with higher wavelength photons. This concept was initially introduced by Jackson in the year 1955 (Jackson, 1955). After that, several researchers performed theoretical and experimental studies on cascade or tandem (Loferski, 1982), multijunction concentrator cells (Hutchby, 1985; Mitchell, 1981). Lamorte and Abbott (1980a, 1980b) reported the design of a two-junction monolithic cascade solar cell using computer modelling, further an optimized design of high-efficiency tandem cell was reported by Fan et al. (1982). Pauwels and De Vos (1981) predicted 42% conversion efficiency for two-cells stacked tandem configuration with optimized band gaps. Tandem design can be implemented using mechanically stacked, monolithically integrated, and spectrally split architecture (Bailie and McGehee, 2015). Gee et al. in 1988 (Gee and Virshup, 1988) reported 31% efficient mechanically stacked GaAs/Si tandem solar cell for concentrator application and Friedman et al. (1995) achieved 30.2% efficient GaInP/GaAs Monolithic two-terminal tandem solar cell for concentrator applications. Several researchers also reported theoretical study of chalcopyrite/c-Si, indium gallium nitride ($In_{0.48}Ga_{0.52}N/In_{0.48}Ga_{0.52}N$), InGaN/Si and a-Si:H/c-Si based tandem devices in the recent and past years (Bencherif et al., 2019; Kim et al., 2017; Marouf et al., 2019; Nacer and Aissat, 2016).

At present, more than 90% of solar PV demand has been roofed by natural abundant, eco-friendly silicon (Si) material (ITRPV, 2019). The rigorous research on c-Si resulted in a record 26.6% efficient Si solar cell (Yoshikawa et al., 2017), which is close to the theoretical limit of 29.4% (Richter et al., 2013) for Si solar cell. Moreover, to boost the

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* Corresponding author.
E-mail addresses: rahul.pandey@chitkara.edu.in, rahulp.electronics@gmail.com (R. Pandey).

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